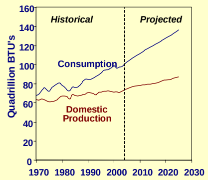
The Hydrogen Economy - When Will We Get There?

Advanced Fuel Processing Catalysts for Hydrogen Production and Fuel Cell Systems

Magali Ferrandon, Chemical Engineering Division

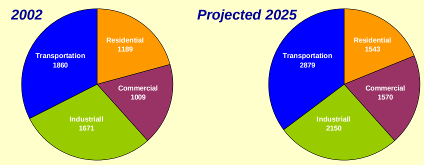
Why a hydrogen economy?

Reduce our dependency on foreign imports



Source: *Annual Energy Outlook 2004 – EIA/DOE*

Reduce CO_2 and other greenhouse gas emissions

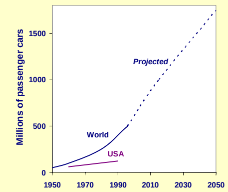


Total = 5729 million metric tons

Total = 8142 million metric tons

Source: *Annual Energy Outlook 2004 – EIA/DOE*

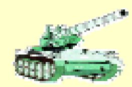
Competition from emerging economies for available resources



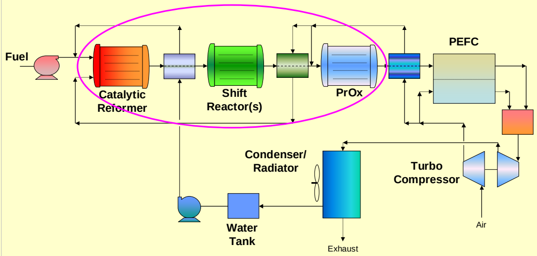
Source: www.volvocars.com

Distributed fuel processing can introduce fuel cell power in the absence of a refueling infrastructure

- ✓ **Transportation -** primary propulsion power for automobiles and light-duty vehicles - auxiliary power units (APUs) for long-haul trucks
- ✓ **Stationary -** distributive residential power generation
- ✓ **Portable Power -** electrical generators
- ✓ **Military Applications -** "Silent Watch"



Fuel processors using catalysts can convert natural gas, liquefied petroleum gas, gasoline, diesel, and renewable fuels such as bioethanol into hydrogen



Fuel processor for polymer electrolyte fuel cell

The first step is to reform the fuel. The reforming processes used include:

Steam reforming (SR)	$C_nH_m + nH_2O = nCO + (n + m/2)H_2$ *(endothermic)*
Partial oxidation (POX)	$C_nH_m + (n/2)O_2 = nCO + (m/2)H_2$ *(exothermic)*
Autothermal reforming (ATR)	$C_nH_m + (n/2 - y)O_2 + 2yH_2O = nCO + (m/2 + 2y)H_2$ *(exothermic or endothermic depending on H:C:O ratio)*

The fuel gas produced by the reformer can contain 10% CO, which can poison the PEFC; thus additional steps are required to reduce the CO amount to 10 ppm:

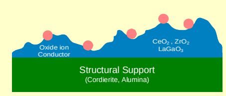
Water-gas shift (WGS)	$CO + H_2O = CO_2 + H_2$
Preferential oxidation (PrOx)	$CO + 1/2O_2 \rightarrow CO_2$

There are issues with using industrial catalysts for small-scale distributed applications

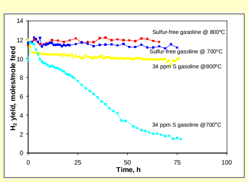
Process	Industrial catalysts	Issues
SR	Ni/α-Al_2O_3	Coking, S intolerance, inactive NiAl spinel, need reduction, pyrophoric
WGS	Fe-Cr and Cu-Zn oxides	Need reduction, pyrophoric, temperature-sensitive
PrOx	Co-Pt on a refractory oxide	Precious-metal catalysts are expensive

Argonne is looking for better catalysts through activity testing, and characterization of "fresh" and "spent" catalysts.

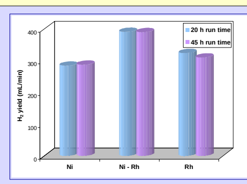
- The goal is to improve the activity and stability of the catalysts, retard coke formation and improve sulfur tolerance.
- For the reforming catalysts, we are focused on the development of **bimetallic formulations** (e.g., Pt, Rh, and Ni) where the support is either an oxide-ion conducting substrate, such as CeO_2, or a refractory oxide, such as Al_2O_3.

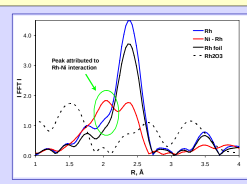


Transition Metal on Oxide-Ion Conductors

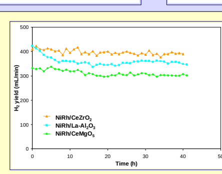


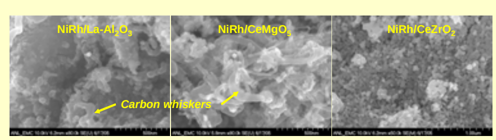
Effect of temperature on the activity for reforming of gasoline without and with ~ 30 ppm sulfur.





Ni-Rh performs better than Ni or Rh alone for the production of H_2 from the steam reforming of n-butane (left chart) due to positive interactions between Ni and Rh (right chart) detected by extended X-ray absorption fine structure analysis (EXAFS) at the Advanced Photon Source (APS).





Ni-Rh/$CeZrO_2$ produces more H_2 than Ni-Rh on La-Al_2O_3 and $CeMgO_5$ from the steam reforming of n-butane (left chart). Carbon whiskers were observed on La-Al_2O_3 and $CeMgO_5$ but not on $CeZrO_2$ (images at right) by scanning electronic microscope (SEM), indicating that $CeZrO_2$ is better able to gasify carbon than La-Al_2O_3 and $CeMgO_5$.

Summary

- The U.S. is moving towards a hydrogen economy
- Distributed production of H_2 will allow entry of fuel cell power
- Reforming of fossil fuels will play a major role in the production of H_2 during the transitional period
- Although industrial-scale steam reforming is a mature technology, new technologies (catalysts and reactor designs) are needed for small-scale distributed production

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